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AN INFORMATION MODEL OF THE EXTRAVEHICULAR DYNAMICS OF COSMONAUT BODY MOVEMENTS AND SPATIAL ORIENTATION

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ABSTRACT

The authors discuss an investigation on an information model of the extravehicular dynamics of cosmonaut body movements and spatial orientation. It is found that a cosmonaut's individual movement control system must include motors to ensure rotation with respect to three mutually perpendicular axes and linear movement, controls, stabilization circuits, and an information model which provides the cosmonaut with data on spatial orientation and movement parameters. Detailed treatment is given to the information model of the control process.

The conquest of outer space and the performance of scientific research /1* work requires man to venture into open space many times and maneuver.

Forward movement in space in a desired direction with respect to the spaceship is impossible without the exertion of force outside the spaceship. Therefore a cosmonaut must have an autonomous propulsion system making it possible to control and stabilize his angular position and also to create linear acceleration when moving outside the spaceship.

A very simple device in the form of a space jet pistol (motor) or a more complex propulsion system can be used as an individual system for controlling orientation, stabilization, and movement.

When using a jet motor (pistol) held in his hands, a cosmonaut, in order to control movement of his center of mass, must direct the axis of the motor so that the line of thrust passes through his center of mass. This is very difficult to do and therefore rotating moments are experienced when trying to control the movement of the center of mass. Uncontrolled rotation of the body is very undesirable since this makes it difficult to control movement of the center of mass and leads to loss of orientation in space by the cosmonaut and to other consequences.

*Numbers given in the margin indicate the pagination in the original foreign text.

If a cosmonaut is close to a spaceship he can easily determine his angular position and the parameters of movement with respect to the ship and make /2 adjustments. When a cosmonaut is a great distance from his ship, however, it is difficult for him to determine the parameters of his movement in space with respect to the ship and decide the cause for its movement in his field of vision, whether it is a result of rotation or the lateral component of the relative velocity.

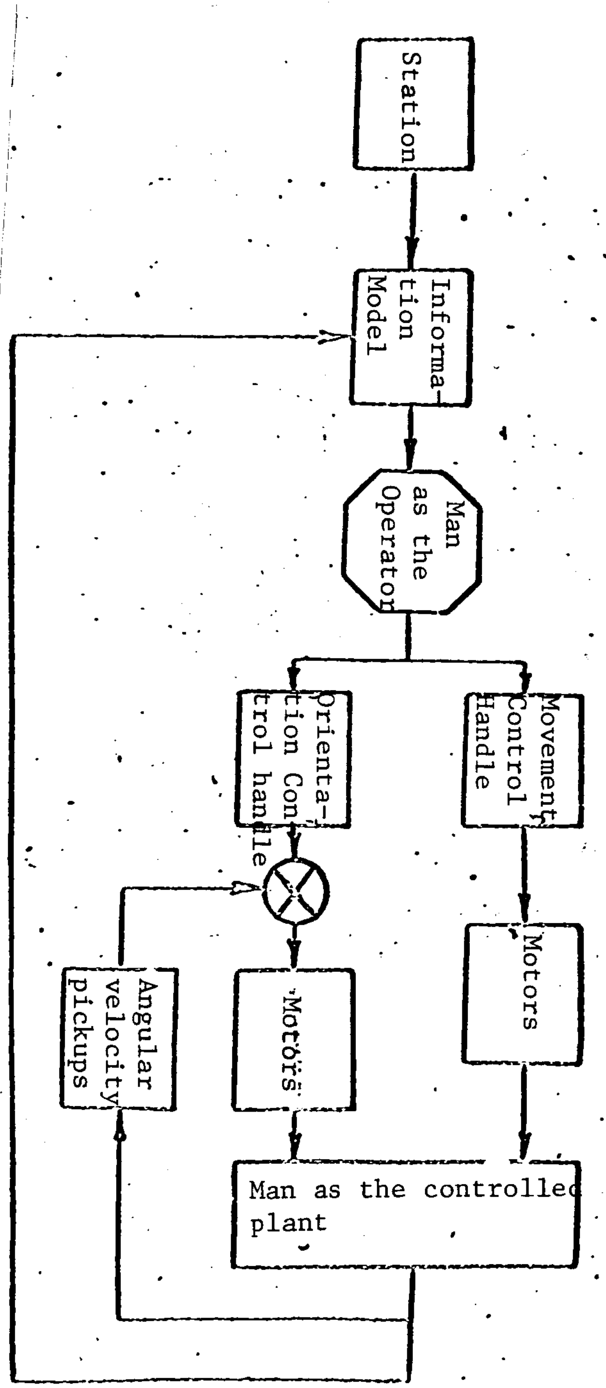
Methods for providing feedback in the control system of an individual propulsion system are rather complex and have not yet been adequately studied. The design of a feedback system will depend on the solution to the problem of spatial orientation by man in outer space.

Information obtained in flying and model experiments give evidence of the extremely limited participation of man's afferent systems in analyzing the dynamics of spatial relations in an autonomous propulsion system. Under conditions obtaining on the ground the capabilities of the stato-kinetic analyzer intended for this purpose are limited by the factor of weightlessness. For all practical purposes orientationless space also limits the functional capabilities of the visual analyzer. All this leads to a need to design special devices which are able to compensate for this limitation on sensory information.

Based on the above an individual system must provide for automatic stabilization of the angular velocity of a cosmonaut at a value close to zero. In this case the cosmonaut will be able to evaluate the lateral component of the speed of movement with a degree of precision determined by the residual speed of rotation. The block diagram of a system of control in such an instance is shown below. In this system the operator gets information on a change in the coordinates of the control process of orientation and movement by observing the change in the size of the image of the spaceship and by its movement in his field of vision while his head is held in a fixed position with respect to his body. The information obtained as a result of taking a sight on the ship which is used as a target is supplemented with information about the position of the stars, the Earth, and the moon against the background of which movement takes place.

In order to influence the control process there is in the system a three-channel linear handle for controlling angular movements with respect to the angles of bank, course, and pitch and also a three-channel relay handle for controlling longitudinal and lateral movement. Use can also be made of the device for converting spoken commands into control signals. Linear and angular acceleration is created by the motors located along appropriate axes of the coordinate system. Angular speed is measured by rate-of-turn gyroscopic pickups.

The cosmonaut can accomplish departure from the spaceship using the method of direct guidance. When exercising control by this method the pilot must orient himself on the ship, switch on the motors, and gather the /4 necessary speed for departure. In the absence of an indicator of the speed of departure, the speed can be estimated from the time of motor operation. The angular velocity of the line of sight which appears as a result of the operation of the motor with imprecise orientation decreases with time since during departure the process of control with respect to the angular velocity of the line of sight is stable. Therefore, during the process of departure there is no need to switch on the motors to dampen the angular velocity of the line of sight.



Block Diagram of Manual Control System for Extravehicular Movement by a Cosmonaut.

After the pilot reaches the prescribed distance he must decrease his speed to zero by turning on his motor for a certain interval of time. Experiments have shown that it is difficult to determine distance and rate of approach (retreat) visually using the observed angular size of the spaceship, especially when the distance is great. The angular size of the spaceship is inversely proportional to the distance, that is, $\beta = B/\rho$ where β is the angular dimension of the spaceship, B is the projection of the linear size of the spaceship on a plane perpendicular to the line of sight, and ρ is the distance. The speed of approach (retreat) is determined from the speed of change of value of β. At a great distance the speed of approach is more difficult to judge than the distance since the speed of change in the angular size is proportional to the speed of approach, ρ , and inversely proportional to the square of the distance, that is, $\beta = B\rho / \rho^2$. This has an effect on the exercise of control.

Experiments to study the control dynamics of movement by a cosmonaut with respect to his spaceship in outer space were conducted on a modeling stand which consisted of a continuous action computer, a mock-up of a propulsion system with the elements for manual control, and an electron-beam oscilloscope. The image of the ship as simulated on the screen of the electron-beam oscilloscope moved and changed dimensions in accordance with the dynamics of control. The operators were given the mission of "retreating" to a distance of 40 meters, stopping, and then returning to the "spaceship." In the absence of instrument information on the relative distance and rate of approach manual control of departure to a distance of 40 meters was done with a mathematical expectation of 41 meters with a root-mean-square deviation in distance of 4 meters and a velocity of 15 m/sec.

When the operator was given instrument information about the relative distance and rate of approach the control process was executed much better. The operators started to pull away to the given distance with a mathematical expectation of 40.1 meters with a root-mean-square deviation in distance of 0.2 meters and a velocity of 2 cm/sec. The operators used the parallel /5 approach method to return to the spaceship. When using this method and the manual control system as shown in the block diagram above, included in the functions performed by the operator are: orientation and stabilization of angular position with respect to the direction of the target, especially at the instant of correction of movement of the center of mass; decreasing the initial angular velocity of the line of sight of the spaceship; selection of the required speed for the approach; and maintaining an angular velocity of the line of sight close to the minimum possible value and decreasing the speed to zero on approaching the spaceship to establish contact with it. To carry out all these operations the cosmonaut must have information about angular position with respect to the direction of the spaceship, the angular velocity of the line of sight, and the relative distance and speed of approach.

Most of the coordinates of the control process can be determined visually by observing the position of the ship in the cosmonaut's field of vision when his head is held fixed with respect to his body. If the control system has a circuit for automatic stabilization of the angular velocity of the body, the cosmonaut, by the movement of the image of the spaceship in his field of vision, is able to determine the angular velocity of the line of sight on the spaceship which makes it possible in controlling lateral movement to dampen it with an accuracy corresponding to the remanent velocity. By using a special procedure the pilot is able to exercise control so that the angular velocity of the line of sight is within the range of values smaller than the value of the remanent angular velocity of rotation of the cosmonaut. This procedure consists of having the pilot make trial movements with the handle first in one and then in the other direction to create a remanent angular velocity of rotation of different signs and by comparing the speed of movement of the image of the ship in a transverse plane with positive and negative remanent velocities of his own rotation to determine the existence of angular velocity of the line of sight.

In case of absence of instrument information on the angular velocity of the line of sight, it is possible to use the variation wherein the pilot of the spaceship observes the angular velocity of the line of sight and sends commands to the cosmonaut moving outside the spaceship to dampen the angular velocity of the line of sight. Such a method of control provides for a high degree of precision in controlling the lateral movement of the center of mass of the cosmonaut. The angular velocity of the spaceship is stabilized with an accuracy corresponding to the remanent velocity to an order which is less than the remanent velocity of the cosmonaut's own rotation outside the spaceship and therefore the pilot can with great precision determine the existence of angular velocity of the line of sight.

Experiments have shown that from a distance of 40-50 meters the pilot can also successfully converge with his spaceship in the absence of instrument information on the distance, approach velocity, and angular velocity of the line of sight. With the existence of instrument information on the distance and speed of approach the characteristic velocity (total gain in velocity in controlling movement of the center of mass) decreased by a factor of 1.2 and the mathematical expectation and root-mean-square deviation of velocity of collision was reduced by more than half. Verbal prompting from the spaceship-target to control the angular velocity of the line of sight also improved the /6 process of control in precision and in characteristic velocity. In experiments the mathematical expectation of the velocity of collision decreased by a factor of 1.5, of the root-mean-square deviation of velocity of collision by a factor of 1.3, and the characteristic velocity by a factor of 1.25 in comparison with control exercised on the basis of information obtained by sighting.

Experiments have demonstrated the usefulness of giving instrument information to the cosmonaut on his distance and speed of approach. The cosmonaut during his stay in open space must, to preserve spatial orientation, resort to the conventional orientation used for space flight in place of the traditional "up--down." He may use as his system of coordinates the system of coordinates based on the axes of the spaceship. This system is also needed by the pilot for him to approach a certain part of the spaceship. For determining the relative bank of the angular position of the spaceship with respect to the line of sight use may be made of the configuration of the spaceship and its structural components (antennas, etc.).

If the spaceship is in the Earth's shadow and not illuminated then to determine its angular position with respect to the cosmonaut it is advisable to use the special reference points (luminous vertical and horizontal strips) placed on the spaceship at a prescribed interval from one another.

When the ship is in a correctly oriented position the reference points appear in the form of a symmetrical cross. When there is some deviation in pitch or angle of yaw the symmetry is disrupted and the strips take the form of a T or an L. If the angle of the course of the pitch is 90° one reference point will be completely visible as a luminous line and the other will appear in the form of a luminous point at some distance from the first. The angle of relative bank is determined from the incline of the cross on a plane perpendicular to the longitudinal axis. In order to differentiate the vertical reference point from the horizontal, one of them must blink. Experiments have shown that the reference marks provide for sufficient precision in determining the angular position of the spaceship if they have an angular size (in length) of not less than 5-7' and if the reference marks are not more than twice as bright as the background.

On the basis of the information obtained during the investigation the following conclusions can be drawn:

A cosmonaut's individual movement control system must include motors which provide for rotation of the cosmonaut with respect to three mutually perpendicular axes and linear movement according to three axes of coordinates, controls, circuits for automatic stabilization of the angular velocity and the information model of the control process giving the cosmonaut the needed information about his spatial orientation and the parameters of his movement.

The effectiveness of movement in space in large measure depends on /7 the information model of the control process.

For solving problems of a cosmonaut's movement in space with respect to the spaceship there is a need for an information model of the control process which provides information to the cosmonaut as follows:

a) angular position of his body with respect to the line "spaceship--cosmonaut" (line of sight) in course and pitch and with respect to the spaceship in bank;

b) angular velocity of the line of sight (lateral component of the relative velocity);

c) approach velocity (or velocity of retreat);

d) relative distance.

The cosmonaut can determine most of these parameters by observation of the spaceship or of parts of it. Experiments have shown that it is difficult to determine visually the relative distance and speed of approach by changes in the size of the image of the object being approached by the cosmonaut. Therefore, instrument information is needed on these movement parameters.

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